In: Proceedings of ANTEM, Symposium on Antenna Technology and Applied Electromagnetics, Dept. of Electrical and Computer Engineering, University of Manitoba, Winnipeg, MB, Aug. 1990. C-CORE Publication 90-30

RADIATION CHARACTERISTICS OF AN ARBITRARILY FED INSULATED LINEAR ANTENNA IN AIR

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ABSTRACT

Analytic expressions are derived for the input admittance and the current distribution along the arbitrarily-fed insulated antenna in air which is excited across a gap of non-zero width. In this work, the Wiener-Hopf type analysis for a center fed insulated antenna is extended to the case of asymmetrically excited antenna. Present analysis which does not employ superposition yields final expressions in terms of the excitation location as well as the aperture electric field within the gap. The results for the input admittance and current distribution are reported for different excitation location, outer radii and dielectric constants of the insulator at various antenna length.

1. Introduction

Usually, a dielectric coating is introduced when contact between the dipole antenna and surrounding medium is either undesirable (corrosive medium) or unavoidable (ice accumulation). Wiener-Hopf type analysis has been efficiently used to derive analytic expressions for the current distribution along the centre-fed dielectric-coated antenna in air [1]. Also, the Wiener-Hopf analysis has been used to analyze the multiply-fed and/or loaded isolated antenna in air [2]. The aim of this paper is to extend the Wiener-Hopf type analysis to the case of an asymmetrically excited insulated antenna in air. Comparison will be made between insulated and isolated antennas' values for both the current distribution and input admittance. The main advantage of the Wiener-Hopf technique is that there is no need to guess at a first approximation for the current. Also, this technique employs reasonably acceptable assumptions in addition to the fact that the solution is in the form of an asymptotic series which gives reasonably accurate results by using only the first series term especially when the antenna is long [2].

2. Derivation of the integral equation

Consider a perfectly conducting cylindrical solid dipole of radius a and length $L = 2h$ ($L >> a$, $\lambda_0 >> a$), where λ_0 is free space wavelength. The dipole has an infinitely long coaxial insulating sleeve of outer radius b and dielectric constant ϵ_r. Let this insulated dipole be excited by a voltage feed V_0 across a gap extending from $z = l-g$ to $z = l+g$ where the gap width is $2g$ and $z = l$ is the feed centre location as shown in Fig. 1. The aperture gap field $E_g(z)$, is assumed to be the Fourier Bessel expression for the infinite insulated antenna $E_{FB}(z)$ [3]; i.e.

$$E_g(z) = E_{FB}(z) = \frac{-V_0}{2g} + \sum_{n=1}^{\infty} A_n \beta_n^2 \cos\frac{n\pi(z-l)}{g}, \tag{1}$$

the electric field on the antenna surface ($-h \leq z \leq h$), is given by

$$E_z(z) = E_{FB}(z)H(z-l-g)H(l+g-z) \tag{2}$$

$H(z)$ is the Heaviside function and the time dependence $e^{j\omega t}$ has been omitted. Employing the above electric field expression in formulating the integral equation (in a similar manner to [1,2]), one finally has,

$$\int_{-\infty}^{\infty} E_z'(z')M(z-z')dz' = -\int_{l-g}^{l+g} E_{FB}(z')M(z-z')dz' + \frac{jI(z)}{kaY}, \tag{3}$$

where

$$M(z) = -\frac{\pi}{2}\int_{-\infty}^{\infty} P(\zeta)e^{j\zeta z}\,d\zeta, \tag{4}$$

and $P(\zeta)$ is defined as follows [3]:

$$P(\zeta) = \frac{2}{\pi\beta}\frac{\beta H_1^{(2)}(\beta_0 b)\, X_z(\zeta) - \epsilon_r \beta_0 H_0^{(2)}(\beta_0 b)\, Y_g(\zeta)}{\beta H_1^{(2)}(\beta_0 b)\, Z_z(\zeta) - \epsilon_r \beta_0 H_0^{(2)}(\beta_0 b)\, R_r(\zeta)} \tag{5}$$

with

$$X_z(\zeta) = J_1(\beta a)N_0(\beta b) - J_0(\beta b)N_1(\beta a), \tag{6}$$

$$Y_g(\zeta) = J_1(\beta a)N_1(\beta b) - J_1(\beta b)N_1(\beta a), \tag{7}$$

$$Z_z(\zeta) = J_0(\beta a)N_0(\beta b) - J_0(\beta b)N_0(\beta a), \tag{8}$$

and

$$R_r(\zeta) = J_0(\beta a)N_1(\beta b) - J_1(\beta b)N_0(\beta a) \tag{9}$$

Where $\beta_0 = (k_0^2 - \zeta^2)^{1/2}$, $k_0 = 2\pi/\lambda_0$. Also, $\beta = (k^2 - \zeta^2)^{1/2}$, $k = k_0\sqrt{\epsilon_r}$. $H_n^{(2)}(z)$, $J_n(z)$ and $N_n(z)$ are the second kind Hankel, Bessel and Neuman functions, respectively, of order n and argument z. $Y(=\sqrt{\epsilon_r}/120\pi)$ is the intrinsic admittance of dielectric coating. Equation (3) holds for all z values provided that the electric field along the antenna extension $E_z'(z)$ vanishes for $|z| < h$ whereas the current distribution $I(z)$ vanishes for $|z| > h$. Applying the Wiener-Hopf technique to the integral equation in a manner similar to that detailed elsewhere [1,2], one finally has the solution of this integral equation in the form of an asymptotic series which gives reasonably accurate results by using the first

order term. Accordingly, for the first order term, the current distribution is in the form,

$$I(z) = kaY\Big\{ [y_0(-k_0)Q_0(h+z) + f_0(k_0)Q_0(h-z)]C_0 + \int_{l-g}^{l+g} E_{FB}(z')Q_0(z-z')dz' \Big\}. \tag{10}$$

The input admittance is the current per unit input voltage at the gap edge, Y_{in} $(= I(l+g)/V_0)$ is in the form

$$Y_{in} = \frac{kaY}{V_0}\Big\{ [y_0(-k_0)Q_0(h+l+g) + f_0(k_0)Q_0(h-l-g)]C_0 + \int_{l-g}^{l+g} E_{FB}(z')Q_0(l+g-z')dz' \Big\}. \tag{11}$$

$Q_0(h)$ is an integral in the complex t-plane and is given by

$$Q_0(h) = \frac{j\pi}{2}\int_{C_+} P(t)e^{-jth}\,dt\ . \tag{12}$$

$f_0(k_0)$ and $y_0(-k_0)$ are two unknowns which can be found by solving the following two auxiliary equations,

$$y_0(-k_0) + f_0(k_0)Q_0(2h)A_{0,0}(-k_0) = -B_{0,0}(-k_0)\int_{l-g}^{l+g} E_{FB}(z')Q_0(h+z')dz' \tag{13}$$

$$y_0(-k_0)Q_0(2h)A_{0,0}(-k_0) + f_0(k_0) = -B_{0,0}(-k_0)\int_{l-g}^{l+g} E_{FB}(z')Q_0(h-z')dz' \tag{14}$$

with

$$A_{0,0}(-k_0) = C_0^2/2k_0 \quad , \quad B_{0,0}(-k_0) = C_0/2k_0 \tag{15}$$

and $C_0 = e^{-T_1}$ where T_1 is given by,

$$T_1 = \frac{1}{2\pi j}\int_{C_-} \frac{\ln m(t)\,dt}{(t-k_0)}\ . \tag{16}$$

The above integral can be modified to be in the form

$$T_1 = \frac{-k_0}{\pi}\int_0^{\infty} \frac{\ln[2\pi P(jk_0v)]}{(1+v^2)}dv\ , \tag{17}$$

which can be evaluated using standard numerical integral routines.

4. Discussion of numerical results

In this work the current distribution and input admittance are plotted for various values of dielectric constant and outer diameter of the dielectric coating on the asymmetrically, singly excited insulated monopole antenna in air. The radius of the inner conducting cylinder, the antenna length and the

location of the voltage excitation will be kept constant during this investigation. Figure 2 illustrates the change in the current distribution along an insulated antenna with the change in the dielectric constant of the dielectric coating which varies from 1.005 to 9 whereas the first value of 1.005 represents the case of isolated antenna in free space. The data in Fig. 2 are reported for an $5/4\lambda_0$ antenna covered by a dielectric shell of $b/a=2$. The antenna whose radius is 0.00318 m, is excited at $z=-h/2$ across a gap of width $2g=7.1a$. At operating frequency of 600 MHz, where the antenna is considered thin ($k_0a = 0.04$), results are reported for three values of ϵ_r, 1.005, 3.2 and 9. It is noted that the real part of the current is more sensitive to the change in ϵ_r than the imaginary part.

Because the integral $Q_0(z)$ of expression (12) has a logarithmic singularity at $z=0$, a minimum value (smaller value of either a or g) has to be set for the argument to avoid the singularity while performing the integral. This can explain why the current is not exactly zero at the monopole end as shown in Fig. 2.

The admittance computed from expression (11) has two contributions; the first is due to reflections at both antenna ends while the second is due to the traveling-wave along a similar antenna with infinite length. Since the shape of the aperture gap field does not have a noticeable effect on the first contribution (as recently reported [1]), the results are reported using the constant field or the zero order term of the Fourier Bessel function expression representing the aperture gap field. In Fig. 3, the input admittance is calculated at different antenna length h/λ_0 for same different values of ϵ_r reported in Fig.2. The antenna is still thin with $k_0=0.08$. The antenna is excited at $z=-h/2$ across a gap width $2g$ $(=2a)$. It is observed that the larger the dielectric constant is, the larger the peak values of both the admittance components and the closer the locations of such peaks toward shorter antenna lengths.

5. Conclusions

Analytic expressions are derived for the current distribution and input admittance of an insulated linear antenna in free space which is asymmetrically, singly excited across a gap of non-zero width. With the accuracy of the results limited to $kb<<1$ and $h/\lambda_0 \geq 0.1$, present analysis is considered unique, especially for long antennas. The theory is based on Wiener-Hopf technique which neither requires a first guess of the current shape nor employs superposition and renders final expressions in terms of an asymptotic series which gives very accurate results by merely retaining its first term. Extension of present work to the case of multiple fed and/or loading conditions is possible. Although experimental or theoretical results are not available for the asymmetrically fed insulated antenna, very good agreement exists between results based on present analysis and other theoretical results in the limiting case as ϵ_r goes to unity (isolated antenna).

References

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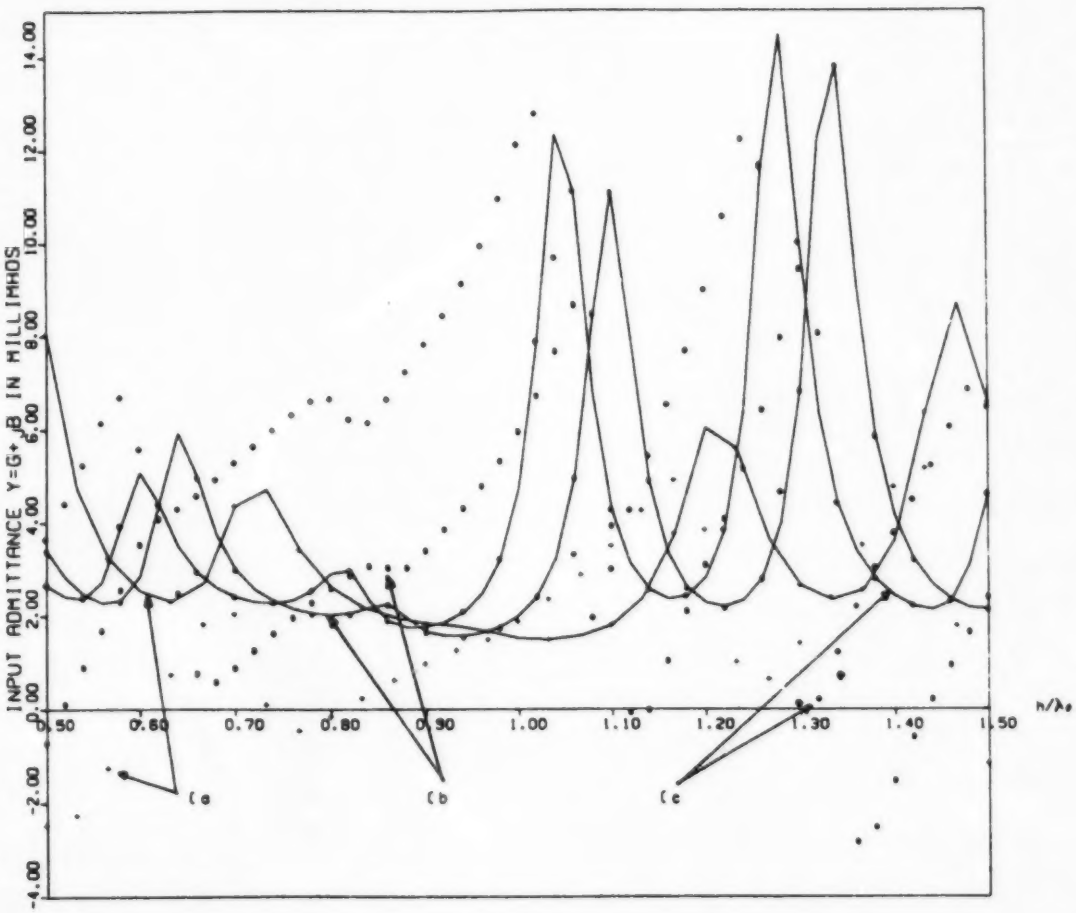

Fig. 3 Input admittance of an insulated antenna of $k_0a=0.08$ excited at $z=-h/2$ with $g=a$, $b/a=2$ for a) $\epsilon_r=1.005$, b) $\epsilon_r=3.2$, and c) $\epsilon_r=9$. (connected and unconnected symbols represent the conductance G and susceptance B, respectively.)

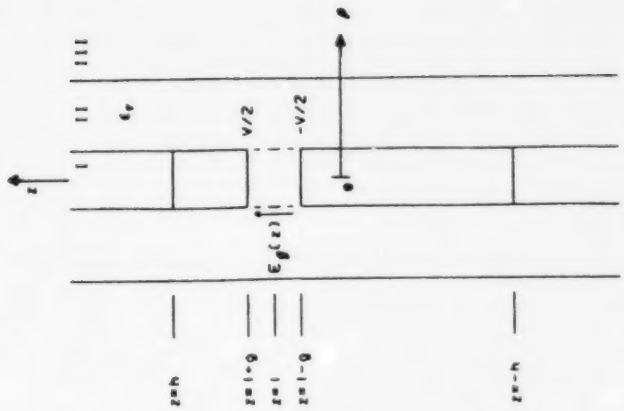

Fig. 1. An asymmetrically fed insulated solid antenna; singly excited across a gap of width 2g

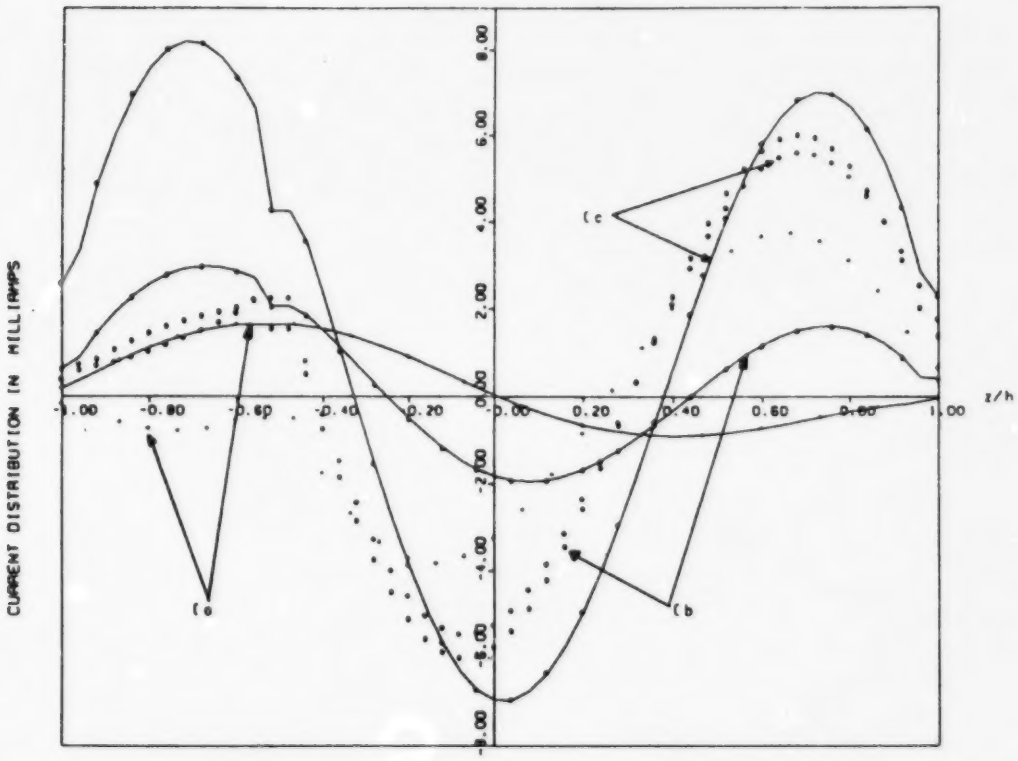

Fig. 2 Current distribution on 5/4 λ_0 insulated antenna of $k_0a=0.04$ excited at z=-h/2 with b/a=2 for a) ϵ_r =1.005. b) ϵ_r =3.2. and c) ϵ_r =9. (connected and unconnected symbols represent the real and imaginary parts of the current, respectively.)